Practical issues in the deployment of a run-to-run control system in a semiconductor manufacturing facility

Stefani, Jerry, Anderson, Mike

Jerry A. Stefani, Mike Anderson, "Practical issues in the deployment of a run-to-run control system in a semiconductor manufacturing facility," Proc. SPIE 3742, Process and Equipment Control in Microelectronic Manufacturing, (23 April 1999); doi: 10.1117/12.346250

Practical issues in the deployment of a run-to-run control system in a semiconductor manufacturing facility

Jerry A. Stefani[a] and Mike Anderson[b]

[a]Texas Instruments, Inc., MS 3701, Dallas, Texas 75243 USA
[b]Adventa Control Technologies, Inc., Dallas, Texas 75243 USA

ABSTRACT

Run-to-run feedback process control for semiconductor manufacturing uses process models to relate the equipment settings to the wafer-state responses of interest. Engineers specify processes in terms of their desired wafer-state effects (the targets), and process models transform these targets into machine settings. To account for drifts and shifts in process behavior, the models are updated to match the current state of the equipment. These tuned, or adapted, models are used to calculate process adjustments to keep the wafer-state responses for subsequent wafers on target. Automatic recipe adjustments reduce wafer processing complexity, increase processing efficiency, and improve processing quality.

Configuring an optimal control strategy for a particular process on a specific tool is fundamental to implementing run-to-run control in a semiconductor manufacturing environment. However, there is a significant effort involved to move from a standalone controller for a single process on a single tool to the deployment of a run-to-run control system across an entire area of the fab or across an entire fab. Some of the key issues include 1) communication between the run-to-run controller and existing factory systems and tool automation, 2) controlling multiple processes per tool and multiple chambers/tools per process, 3) handling non-production runs, and 4) non-constant data sampling due to metrology delays.

ProcessWORKS, a factory-level run-to-run control architecture, originally developed at Texas Instruments and now a product of Adventa Control Technologies, can treat complex control problems in an automated, predictable, and repeatable fashion. ProcessWORKS is compatible with different techniques for data acquisition and analysis, model adjustment and feedback, and model optimization. ProcessWORKS is also designed to deal with practical implementation issues in the fab. In this talk we will review the benefits of ProcessWORKS run-to-run control. We will discuss some practical problems in the deployment of run-to-run control in the fab, and we will show how ProcessWORKS deals with these issues. Examples from the deployment of ProcessWORKS at Texas Instruments on state of the art semiconductor technologies will be given.

Keywords: ProcessWORKS, run-to-run process control, advanced process control, model-based process control, semiconductor manufacturing, factory-level advanced process control

1. INTRODUCTION

Advanced process control (APC) has been recognized as an enabling technology for meeting the increased processing efficiency and product quality demands which will drive the future profitability of semiconductor manufacturing facilities. The building blocks of an advanced control system are industrial-quality APC methods, sensor and diagnostic technologies, and integration tools. The introduction of new sensors and process diagnostic tools, the maturation of existing technologies in these areas, and the development of integration tools and methodologies are making the application of APC methodologies a reality for the industry. One focus area for the application of APC techniques is run-to-run (RtR) model-based process control[1-8]. RtR process control is in the final development stage, with initial results demonstrating significant improvement in wafer processing efficiency and product quality (in terms of increased process capability, decreased product scrap, test wafer savings, reduced machine downtime, and increased wafer throughput).

Semiconductor processing is usually done with equipment-dependent, fixed recipes. The resulting wafer-state measurables are typically tracked using statistical process control (SPC) techniques. SPC detects deviations in the process above the noise in the system which are due to a sustained anomalous behavior of the equipment. When SPC discovers an "out-of-control" situation, the process is re-centered via engineering intervention, or the hardware is cleaned up and

Part of the EUROPTO Conference on Process and Equipment Control in Microelectronic Manufacturing ● Edinburgh, Scotland ● May 1999
SPIE Vol. 3742 ● 0277-786X/99/$10.00

recommissioned in hopefully the original in-spec state. By eliminating the option of control actions, however, SPC excludes opportunities for reducing the variability in the output of a process. Indeed, such control actions are sometimes so clearly needed that they are practiced together with SPC, but in an ad hoc manner. Examples are the retuning of a process after a maintenance operation and adjusting for gradual drifts in the process such as those caused by the aging of reactor components and consumables. It would be better to monitor the process on a run to run basis and make small adjustments to the equipment settings to keep the wafer-state responses on target. These process adjustments, or feedback control, increase machine uptime by producing more good product prior to an "out-of-control" condition. Simultaneously, process capability is increased.

RtR feedback process control uses process models to relate the equipment settings to the wafer-state responses of interest. Engineers specify processes in terms of their desired wafer-state effects (the targets, such as film thickness), and process models transform these targets into machine settings (e.g., deposition time). The models are updated to track drifts and shifts in process behavior. These tuned, or adapted, models are used to calculate process adjustments to keep the wafer-state responses for subsequent wafers on target. In the old paradigm fixed machine settings resulted in higher variability in product quality while maintaining minimum variability in operating conditions. In the new paradigm the variability in output quality is reduced at the cost of increased variability in operating conditions.

RtR process control often results in reduced wafer processing complexity, increased processing efficiency, and improved processing quality. The reduced complexity arises because the controller separates the process and machine dependencies, thereby allowing the operators the freedom from monitoring these differences themselves. The process model captures the process dependency, and model tuning captures the machine dependency. The increased efficiency is due to the decreased number of test runs required to effectively control a process. Model tuning is accomplished with data from production-based monitors, eliminating the need for test runs. Reduced test runs and inspection time result in increased equipment availability and decreased manufacturing cycle time. Finally, the separation of process variation from machine variation allows the controller to better estimate the machine state and utilize this information to increase the product quality. Increased product quality is associated with improved process performance, such as process capability, or C_{pk}.

The ProcessWORKS advanced process control system, a product from Adventa Control Technologies, Inc., performs run-to-run model-based process control for semiconductor manufacturing equipment. Over the last five years, the ProcessWORKS system has evolved from isolated implementations of RtR process control in Texas Instruments wafers fabs to a solution for advanced process control across TI. The primary thrust of ProcessWORKS deployment in TI wafers fabs now is as a factory-level tool, integrated with our existing manufacturing execution system (MES).

Configuring an optimal control strategy for a particular process on a specific tool is fundamental to implementing RtR control in the wafer fab. However, there is a significant effort involved to move from a standalone controller for a single process on a single tool to the deployment of a RtR control system across an entire area of the fab or across an entire fab. Some of the key issues that have arisen include integration with existing factory equipment and MES, comprehending multiple processes/machines/products, working with different equipment configurations such as multi-chamber, single wafer tools, and comprehending non-production runs, measurement delays, and data correction. Satisfactory resolution of these issues is critical to the success of a RtR control system. Along the way, ProcessWORKS has incorporated the lessons learned form the deployment of a run-to-run control system in production wafer fabs at TI. ProcessWORKS is now a market-ready semiconductor solution for advanced process control.

In this paper, we will cover practical implementation issues for a RtR process control system in a production wafer fab. In Section 2 we provide a brief explanation of RtR model-based process control and its benefits. This explanation leads to a description of the ProcessWORKS advanced process control system. We then discuss in Section 3 practical issues for the deployment of ProcessWORKS in wafer fabs. Examples from the deployment of ProcessWORKS at Texas Instruments on state of the art semiconductor technologies will be given in Section 4.

2. EXPLANATION OF RUN-TO-RUN PROCESS CONTROL AND ITS BENEFITS

2.1 Run to run feedback process control defined

Supervisory control of film thickness using time as the manipulated variable is the most common example of RtR process control for semiconductor processing. Its popularity is due to a general lack of real-time process endpointing sensors for deposition processes. In addition, film thickness metrology is widespread and relatively fast. The control may or may not be automated, e.g., it may be equations written in a lab operations book for the operator to transact on a calculator. The goal of RtR process control is to automate these existing control methods.

Figure 1 shows measured film thickness (optical) versus time for a representative oxidation process used to grow films of various thicknesses. To control this process, an engineer typically maintains an estimate of the oxidation time for each target. Process times are adjusted to account for equipment disturbances. Monitor wafers are usually measured to keep track of the process behavior at each target. Depending on the frequency of wafer starts at each target thickness, test runs are often required to keep times updated. Test runs are expensive and time-consuming. RtR process control can automate the procedure and eliminate test runs.

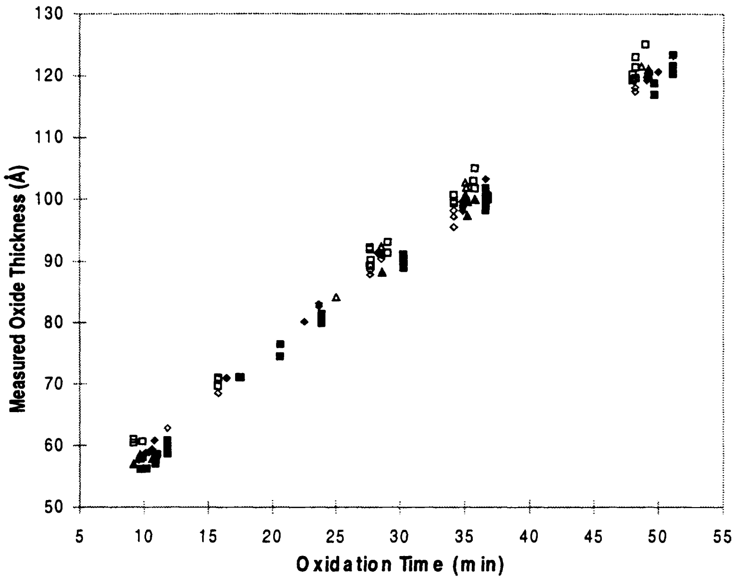

Figure 1. Measured oxide thickness (Å) versus oxidation time (minutes) for furnace oxidation.

Figure 2 provides a simple illustration of RtR model-based process control for a linear system with no noise and no model mismatch (i.e., the slope of the original model equals the slope of the true model). The solid line is the original (un-tuned) model (Output (y) = m•x + b, where x is a setting.) The model is solved to determine which value of x will give an output equal to the target value of 12 (x = (12-b)/m = 2.3). Wafers are run at this input value. Suppose the measured output is lower than the expected value (target) due to machine aging which occurred subsequent to model creation. The model is then updated by adjusting b, the constant term, so that the model would predict the output values measured (Tuned output = m•x + tuned b, i.e., the dashed line in Fig. 2.) The model is re-solved, and wafers are run at the new setting. Now the measured output is on target. While Fig. 2 is a simplistic example, this method has been extensively demonstrated to work for the situation of non-linearity, noise, and model mismatch. It is the constant term which is assumed to need tuning in Fig. 2. In more complicated model-based control methods, some of the other coefficients, or gains (e.g., the slope), may also be tuned.

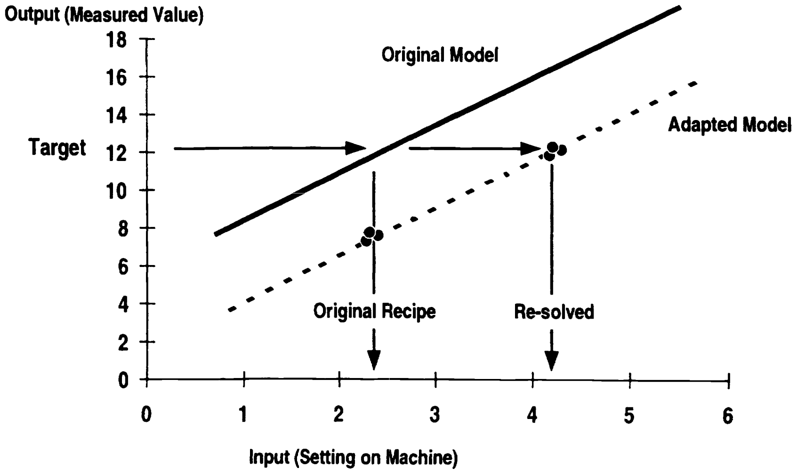

Figure 2. Illustration of model-based process control.

Figure 3 shows an architecture for a model-based RtR controller. At the center of this architecture is the process model itself. The model is optimized to meet desired goals based upon a chosen solution strategy (e.g., tradeoffs between different goals, input step size between runs, etc.) and any feedforward data (the results from earlier processes). The predictions are compared to the measured data, and the model is tuned in accordance with an adaptation strategy. For any run, if the controller cannot solve within an acceptability range, or tune within an allowable range, or the data is not compliant with expected behavior, then the controller takes appropriate action (email/page engineer, shut down tool, etc.). The strategy of how to solve the model, what algorithms to use for data reduction, when to tune the model, how to tune the model, what

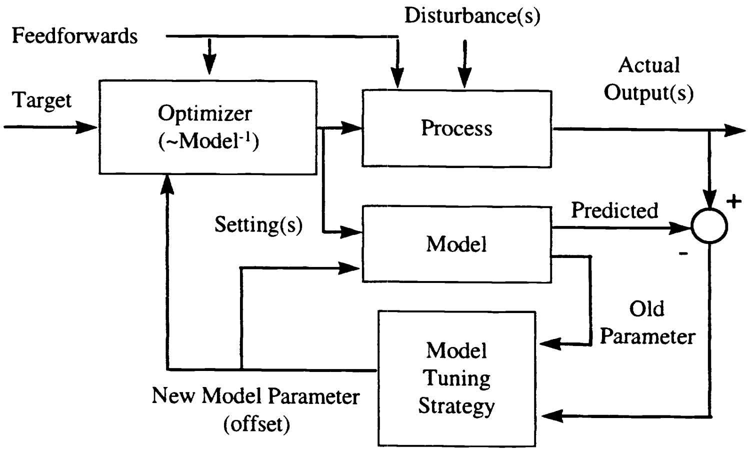

Figure 3. Model-based process control architecture.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.